

# Design Decision-making towards Energy-efficiency Upgrades of Residential Building Façade Refurbishment



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## Abstract

Due to the low-regulated but high energy consumption residential stock and the energy standards required in China, awareness has been raised that refurbishment of the existing residential buildings is the solution to upgrade energy-efficiency. Cities in Northern China, such as Beijing, Harbin, Shenyang and Dalian, have conducted residential refurbishment for years. However, the design of refurbishment is often problematic, resulting in the malpractice of monotonous forms and fuzzy performance. Regulations and standards that come mostly as energy-consumption requirements fail to guide specific design solutions and to address the diversity of individual projects. The applied retrofit methods can be only measured at the end of retrofitting construction process, with little indication for design. Therefore, this paper aims at a design decision-making approach to address detailed design strategies and support energy-efficiency refurbishment of residential buildings. Based on itemising residential building facade components, collecting existing façade constructional information, and compiling green design strategies on façade system, the energy performance of each green design strategy is evaluated. Integrated design strategies, in accordance with the evaluated results, are proposed. Then those integrated strategies are systematically assessed with computer simulations and physical model testing for optimisation and informed choices. This approach can provide integrated green design strategies that quantify the impact of residential building facade components refurbishment, as well as decision-making information towards energy-efficiency upgrade for designers and related groups, such as contractors and home owners.

**Keywords** - residential building, green strategies, energy-efficiency, upgrade, refurbishment



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## 1. Introduction

In the recent two decades, the level of urbanization in China has been raised along with the rapid development of urban residential building construction, and cities have retained enormous residential building stock. However, due to the rapid development, the existing residential building stock cannot meet the increased living requirements, and awareness has been raised that refurbishment of the existing residential buildings is the solution to improve living qualities. On one hand, refurbishment instead of demolition has advantages in economic, cultural, social, and environmental aspects, as well as holding a sense of belonging. On the other hand, there is a relatively large possibility to reduce energy consumption of existing residential buildings, due to the low energy conservation design standard, especially in the Northern China heating areas. Energy efficiency upgrade of existing residential buildings is of great significance.

During the "Twelve-Five" period of China, cities in Northern China heating areas, such as Beijing, Tianjin, Harbin, Shenyang, and Dalian, had conducted residential refurbishment for years and achieved phased progress. But according to the preliminary investigation on those refurbishments, problems still exist, as follows:

1. There is lack of basic database for existing residential buildings, leading to targeted strategies deficiency;
2. Regulations and standards that come mostly as constructional requirements fail to guide specific design solutions and address the diversity of individual projects;
3. The effect of the existing residential building refurbishments cannot be quantified, resulting in the malpractice of monotonous forms and fuzzy performance;
4. The design planning is overlooked in the early stage and the applied refurbishment methods can be only measured at the end of refurbishment construction process, with little indication for future design.

Based on previous research studies and a number of case studies, more than one third (36%) energy consumption can be reduced from early stages of design (Mario Cucinella Architects, 2016). Moreover, in the design of sustainable architecture, the most important strategies are strengthening the thermal performance of building envelopes and using passive strategies to reduce the basic energy consumption, shown as Figure 1 (Rodriguez. 2012; Xing, Hewitt & Griffiths, 2011).

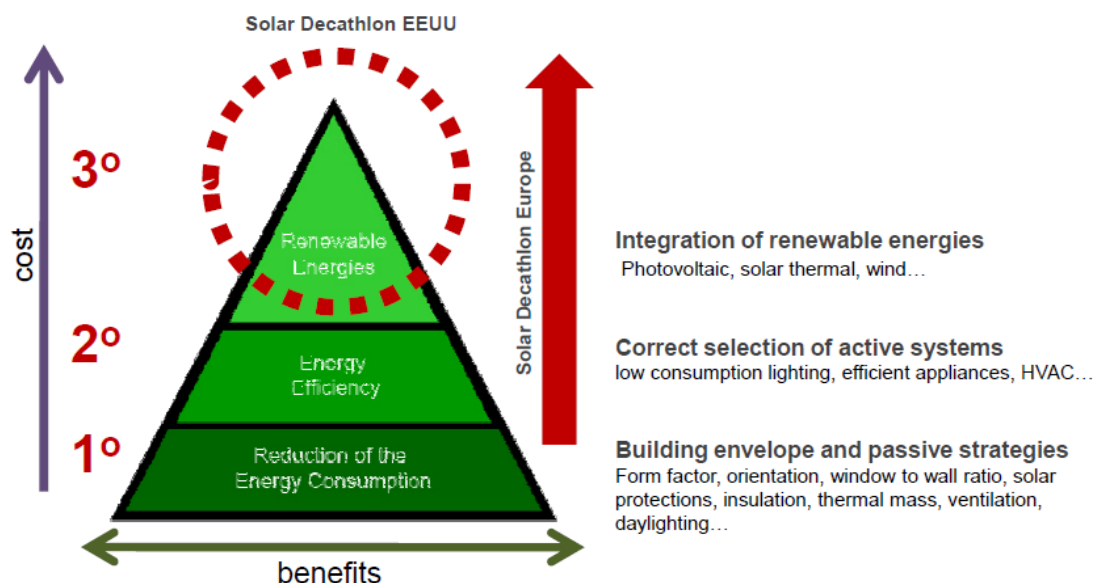


Figure 1: Costs and benefits of sustainable strategies (Rodriguez, 2012)

Therefore, to solve the problems of refurbishing existing residential buildings in China, the direction of this research study is defined as using passive green building design strategies to improve energy efficiency in existing residential buildings. This study takes the existing residential buildings built in the 1980s and 1990s in Northern China heating areas as research objects, aiming at a design decision-making approach to address detailed design strategies and support energy-efficiency refurbishment of residential building facade.

## 2. Objectives

Based on the issues of existing residential building refurbishments and the aim of this study, the objectives of this research include:

1. To investigate and understand the classification and typification of existing residential buildings: In this study, the constituent elements of existing residential building facade in Northern China heating areas need to be classified and compiled. This classification and typification is beneficial to understand the complexity of the existing residential building conditions. It is also the theoretical basis to simplify the design process dealing with building envelope elements;
2. To select suitable passive design strategies: Appropriate passive design strategies are the basis for refurbishment design. The criteria of selecting appropriate passive design strategies rely on the full use of simulation and measurement technology;
3. To establish a scientific evaluation system: Comparative analysis and quantisation effects are the core standards and basis to evaluate selected passive design strategies. The integrated passive design strategies on each building envelope element are comprehensively evaluated, and then the optimal integrations of appropriate passive design strategies that can meet the targeted energy consumption are selected as means for refurbishment.

## 3. Theoretical Framework

A research framework represents the whole research process from the very beginning to the end. Base on a framework, a research study can be expended to detailed research contents and design approaches. According to the research objectives, the framework of this study can be shown as follows:

1. To investigate no less than 80 1980s-1990s typical existing residential building case studies in Northern China heating areas by large-scale data acquisition method. The gathered data of investigated case studies are used for the classification and typification of existing residential buildings;
2. To select appropriate passive design strategies. Passive design strategies are arranged to establish a database from which design strategies can be chosen for the final integrations;
3. To form an existing residential building refurbishment information model for each to be refurbished residential building. The information model is based on the classification and typification of existing residential buildings and passive design strategy database;
4. To calculate and quantify the energy consumption for heating and cooling of each to be refurbished residential building with integrations of passive design strategies by computer simulation and physical model testing;
5. To make an energy consumption target for each to be refurbished residential building;
6. To select the design integrations those meet the targeted energy consumption and make adjustments for optimisation.

## 4. The Research Contents and Approaches

### Research Content 1: Classification and typification of existing residential building facade

Due to the different conditions (built time, structural types, construction methods and degrees of aging) of existing residential buildings, classification and typification of existing residential building facade is beneficial to understand the complexity of the building conditions and to simplify the

design process. Classification refers to the facade components that have great influence on the overall thermal performance. Based on the residential building case studies (shown in Figure 2), the facade components can be concluded as external walls, windows, roofs, balconies, and stairwells. Typification means each component's types of construction materials, insulation measures, thermal performance, and with or without special configuration on structural node. Figure 3 presents a typification of external walls in Dalian City, China.

Prototypes of existing residential buildings can be summarised by the classification and typification, together with considering the shape coefficient of buildings, the facade orientations, and glazing ratio of existing residential buildings.



Figure 2: Case studies of residential buildings (based on case studies in Dalian, China)

Dalian Residential ratio (By 2006)	0%	about 45%	about 30%	about 25%				
Design standard for energy efficiency residential buildings in severe cold and cold zone	JGJ26-2010 (2010)	JGJ26-95 (1995)	JGJ26-86 (1986)	None Standards				
Standards	Heat transfer coefficient of building envelope $K_m (W/m^2 \cdot K)$ Shape factor $\leq 0.3$ Roof: 0.45 Facades: 0.60 Shape factor $> 0.3$ Building envelope Thermal performance tradeoffs judgment (based on Heat consumption)	Heat transfer coefficient of building envelope $K_m (W/m^2 \cdot K)$ Windows: 4.70-4.00 Shape factor $\leq 0.3$ Roof: 0.80 Facades: 0.90 (1.16) shape factor $> 0.3$ Roof: 0.60 Facades: 0.55 (0.82)	shape factor should be controlled at 0.30 or less Heat transfer coefficient of building envelope $K_m (W/m^2 \cdot K)$ shape factor $\leq 0.28$ $K_m \leq 1.80$ 0.30-shape factor $\leq 0.32$ $K_m \leq 1.80 \times 0.95 = 1.71$ 0.32-shape factor $\leq 0.34$ $K_m \leq 1.80 \times 0.9 = 1.62$ 0.34-shape factor $\leq 0.36$ $K_m \leq 1.80 \times 0.8 = 1.44$	None Standards				
	1995 standard		1986 standard	None Standards				
Facades insulation	Sandwich insulation	Internal thermal insulation with an air layer	External wall insulation	Internal wall insulation	Internal wall insulation	Internal wall insulation	Plastered brick wall	Plain brick wall
Illustration								
Structure	1 Interior layer 2 Sandwich wall insulation (Sandwich concrete block) (Sandwich cast-in-place concrete) 3 Exterior layer	1 Interior layer 2 Insulation board (Inflatable gypsum board) (Cement polystyrene board) 3 Air layer 4 Wall 5 Exterior layer	1 Interior layer 2 Wall 3 An adhesive layer 4 Insulation (EPS) (Polystyrene board) (Cement polystyrene board) 5 Protective layer 6 Exterior layer	1 Pebble mortar 2 Solid brick	1 Interior layer 2 Insulation (EPS) 3 Air layer 4 Solid brick	1 Interior layer 2 Insulation (Rock wool board) (Hollow brick) 3 Solid brick	1 Interior layer 2 Wall (Solid brick) (Hollow brick) (cavity wall) 3 Exterior layer	1 Interior layer 2 Wall (Solid brick) (cavity wall)
	1995 standard		1986 standard	1986 standard		None Standards		
Roof insulation				Invert the waterproof layer	External insulation with an air layer	Outer roof insulation	Outer roof insulation	Inner roof insulation
Illustration								
Structure				6 The protective layer 5 Spacer layer 4 Insulation 3 Waterproof layer 2 Leveling layer 1 Roof	6 Waterproof layer 5 Cement 4 Aerated Concrete 3 Air layer 2 Cement casider 1 Roof	4 Waterproof layer 3 Cement 2 Aerated Concrete 1 Roof	2 Foam concrete 1 RC flat roof	2 Waterproof roofing 1 Polyethylene foam board

Figure 3: Regulations and typification of facade constructional information

**Research Content 2: Compiling and selection of appropriate passive design strategies**

Passive design strategies that can be used as means for the refurbishment of residential building facade system are selected and compiled (Figure 4). Active strategies that can upgrade the energy efficiency, such as efficient heating equipment, renewable energy technologies, and other retrofit methods that can affect existing residential building energy-efficiency, such as increasing floor numbers, alternation of the internal space, are not considered in this study.

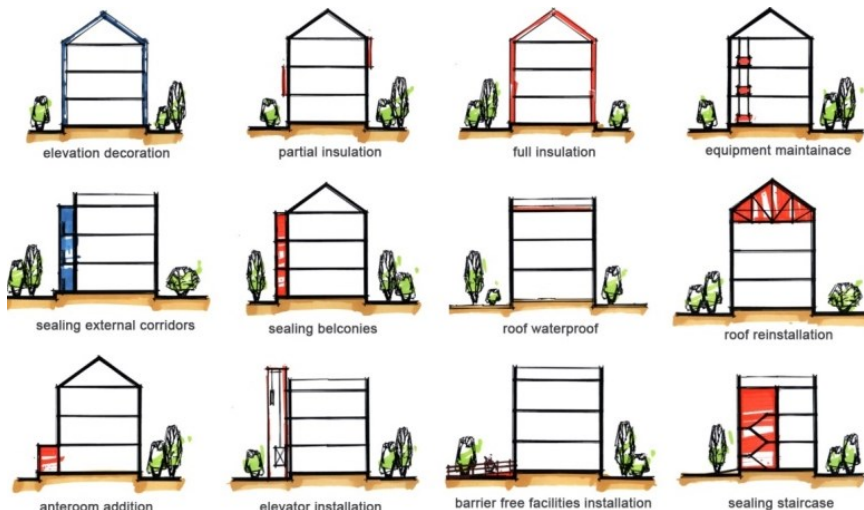


Figure 4: Existing refurbishment approaches on building facade system (partially)

Based on the Research Content 1 and 2 (itemising residential building facade components, collecting existing facade constructional information, and compiling passive design strategies on facade system), a residential building refurbishment information model can be formed. A model

consists of building facade information, passive design strategies used in winter and summer, as shown in Figure 5. This model is the fundamental information for Research Content 4, 5, and 6 for further integrations and simulations of energy performance.

existing buildings Living Information Model	Building facade information					Facade facing	Window to wall ratio
	Wall (structure/Thermal Conductivity)	Roof (structure/Thermal Conductivity)	Windows (structure/Thermal Conductivity of glasses)	Balcony (Floor/Thermal Conductivity/Envelope/Thermal Conductivity)	Staircase (Window / door entry)		
Housing Basic Information	Brick structure/No insulation	Pitched roof/Utility room/No insulation	Single window/3.2	Continuous floor/No insulation/Envelope/No insulation	Single window/3/No door	S	50%
	Lightweight concrete block/No insulation	Flat roof/No insulation	Double window/2.8	Continuous floor/Insulation 1.1/Envelope/No insulation	Double window/2.9/No door	N	30%
	Hollow brick/Insulation 0.8	Flat roof/Insulation 0.7	—	Broken beams floor/No insulation/Envelope/No insulation	Single window/2.8/Exterior doors	E	18%
	—	Pitched roof/Insulation 0.55	—	Broken beams floor / insulation 0.7 / Envelope/insulation 0.7	Double window/2.6/Exterior doors	W	15%
Winter Design Strategy	Air interlayer insulation	pitched roof insulation	Expand the window area	Full insulation	Window replacement	S	%
	Exterior Insulation	Increase pitched roof/add roof insulation	Single glazed windows	floor insulation	additional window	N	%
	Double - skin façade/Single-layer glass curtain wall	flat roof insulation	additional glazed windows	envelope insulation	additional door entry	E	%
	Double - skin façade/Double-layer glass curtain wall	—	Window replacement	Enclosed balcony	Enclosed stairwell	W	%
Summer Design Strategy	Double-skin façade	Roof plants	Horizontal shading	—	—	S	%
	—	Insulation cushion	Increasing the open window area	—	—	N	%
	Dry hanging ceramic plate curtain wall ventilation	Roof ventilation	Mechanical ventilation	—	—	E	%
	Facade planting	Flat roof to pitched roof	Vertical shading	—	—	W	%

Winter design strategies to enhance the various components of the building envelope insulation and thermal performance  
Summer design strategies to improve the focus and efficiency of the main building ventilation window sunshine

Figure 5: Residential building refurbishment information model (with exemplary strategies)

### Research Content 3: Energy consumption simulation

According to the climatic conditions in Northern China heating areas, this study simulates energy consumption by using existing residential building prototypes that Research Content 1 provides. Energy consumption measures winter heating and summer cooling energy demand. The standards for heating and cooling are in accordance with temperatures that maintain the indoor thermal comfort and prevent overheating. Figure 6 illustrates the heating energy consumption requirement in winter as an example. The simulation is calculated by hour, year-round basis, and the unit of measurement is kWh / m2 per year. This study does not consider the forms of heating or cooling source.

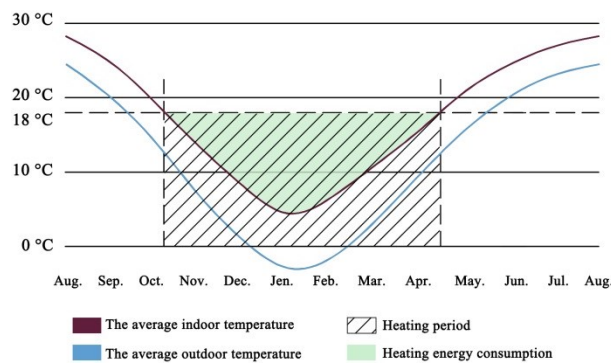


Figure 6: Energy consumption for heating in winter (based on the climate of Dalian, China)

#### **Research Content 4: Energy-efficiency upgrades comparison**

Each compiled passive design strategy is applied on existing residential building prototypes. The effects are simulated, and the energy consumption reduction of refurbished prototypes is calculated and compared with the energy consumption of pre-refurbished prototypes. The higher a reduction is, the more effective the compiled passive design strategy can provide on energy efficiency upgrades. It is worth noting that the total value of building energy efficiency upgrade is not the sum of value every passive design strategy offers. The improved value of each passive design strategy only reflects the impact of this strategy on the effect of improving the overall energy efficiency. Theoretically, each applied strategy plays a role in the promotion of building energy efficiency. However, the real effect of energy efficiency upgrade depends on the suitability of strategies and conditions of existing residential buildings, such as building shape coefficient, facade orientation, and glazing ratio.

Both Research Content 3 and 4 take the computer simulation as the key research method. DesignBuilder was chosen as the computer simulation software in the design stage: DesignBuilder is based on building energy simulation programs (EnergyPlus), checking building energy, carbon emission, day-lighting, natural ventilation and comfort performance. In this study, DesignBuilder provides advanced modelling tools, and enables measurement and assessment of building facade related thermal performance, visual effects, and energy consumption.

#### **Research Content 5: Optimization for the integrated passive design strategies**

Integrated design strategies, in accordance with the evaluated results from Research Content 4, are proposed. Then those integrated strategies are systematically assessed with computer simulations and physical model testing for optimisation.

Together with computer simulation, physical model testing platform is also a method in this study to calculate the energy consumption. Prototypes and refurbishment strategies of existing residential buildings are physically modelled in a large scale, focusing on the construction typification of facade components (external walls, windows, roof structure, balconies and staircases). The results of physical model measurements are used for analysing and optimising the effects of the integrations of passive design strategies. Physical model testing also verifies the feasibility and operability of computer simulations.

## **5. Discussions**

This research study attempts to explore a design approach to improve energy efficiency in existing residential buildings by utilising passive design strategies. The study takes existing residential buildings built between 1980 and 2000 in Northern China heating areas as research objects. This study can provide integrated passive design strategies that quantify the impact of residential building facade components refurbishment, as well as decision-making information towards energy-efficiency upgrade for designers and related groups, such as contractors and home owners.

The research methods involve case studies and energy performance calculation. Existing residential buildings in different cities of Northern China heating areas are investigated. And based on the case studies, the early stage of this study has laid a solid foundation for energy performance calculation. The key methods of energy performance calculation rely on computer simulations and physical model testing. These approaches are relatively reliable and repeatable. However, the feasibility of this method has not been fully verified due to time limits. A comprehensive consideration of inspection process is needed in the future research plan.

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